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# Fiscal Year Spreading of Software Dollars

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# DERIVATION OF THE ENDPOINTS OF A TRIANGULAR DISTRIBUTION WHEN ONLY THE 10TH AND 90TH PERCENTILE POINTS AND MODE ARE KNOWN

This report derives a closed form solution which determines the endpoints of a triangular distribution when only the 10th and 90th percentile points and mode of the distribution are known. The closed form solution can easily be implemented in LOTUS and EXCEL spreadsheets. This solution has been a breakthrough in cost risk analysis since it reduces simulation runtimes and increases the options for using cost risk simulation models.

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# Fiscal Year Spreading of Software Dollars

## BACKGROUND

Our Task Order 42 team has developed several funding profiles based on a specific software development process, coupled with a high order development language. In many cases, especially in Government contracts, the development process and development language are specified.

## PURPOSE

The purpose of this project was to develop a fiscal year spreading methodology and suggested profiles for time-phasing Strategic Defense Initiative Office (SDIO) software cost estimates. Phasing effort by fiscal year results in an obligation profile that is suitable for use in budget formulations.

## SCOPE

This report applies to the fiscal year phasing of software costs associated with SDIO projects. Obligation profiles, presented in this report, apply to all SDIO systems regardless of development language or system complexity. The profiles are based on a software system meeting full DoD-STD-2167A documentation requirements. This report considered only the fiscal year spreading of the Software Development Phase of the System Life Cycle. Figure 1 compares the Software Development Phase to the total System Life Cycle. The purpose of this figure is to orient the reader with the relationship between the Software Development Phase and the total System Life Cycle.

**Figure 1. System Life Cycle[1,2]**

<table>
<tr><td></td><td colspan="4">SOFTWARE DEVELOPMENT PHASE</td><td></td><td></td></tr>
<tr><td></td><td>REQUIREMENTS</td><td>DESIGN</td><td>CODE</td><td>TEST</td><td></td><td></td></tr>
<tr><td colspan="2">DEMONSTRATION & VALIDATION PHASE</td><td colspan="3">ENGINEERING & MANUFACTURING DEVELOPMENT PHASE</td><td>PROD PHASE</td><td>OPS & SPT PHASE</td></tr>
</table>

[1] **Ada Parametric Sizing, Costing and Scheduling**, William G. Cheadle, Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201 (paper presented at the 1987 ISPA Conference held 5-7 May in San Diego, CA

[2] **SASET Training Course**, William G. Cheadle, 16 - 17 December 1992, Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201

The Software Development Phase begins during the Demonstration and Validation Phase (DEMVAL) and is typically completed when the Engineering and Manufacturing Development Phase (EMD) ends. During system production, the completed software is placed under rigorous configuration control and any changes are handled in the same manner as fielded software with managed releases and centralized implementation control. The funding category for the completed software depends on the life cycle phase of the overall system (i.e. Research & Development (R&D), Production, or Operations and Support (O&S)). For example, during system production, the completed baseline software system configuration is maintained with production money. After fielding, software is maintained with O&S funding.

In Figure 2, the Software Development Phase is further decomposed to show sub-phases and major design reviews. The profiles in this report include the costs of the development phase, including all reviews and documentation requirements through hardware/software integration shown in Figure 2. Production and Operations & Support profiles are not included within the scope of this report.

**Figure 2. Software Development Phase (DoD-STD-2167A)[3,4,5]**

SPR SRR SDR SSR PDR CDR TRR
FCA/PCA FQR

| REQUIREMENTS | | | DESIGN | | CODE | | TEST | | |
|---|---|---|---|---|---|---|---|---|---|
| SYS CONCEPT | SYS/SW RQMTS ANALYSIS | SW RQMTS ANALYSIS | PREL DESIGN | DETAIL DESIGN | CODE | UNIT TEST | CSC INFORMAL INTEG | CSCI FORMAL TEST | SYSTEM INTEG TEST |

DoD-STD-2167A, Defense System Software Development, which is the current development standard establishes uniform requirements for software development that are applicable throughout the system life cycle. It provides the basis for Government insight into a contractor's software development and does not specify or discourage the use of any particular software development method. DoD-STD-2167A provides the framework for any software development methodology (i.e., the products, processes, and controls), a standard set of terminology, and a phase breakdown. In addition to the phase breakdown, DoD-STD-2167A identifies required milestones, and provides a Contract Data Requirements List (CDRL) with

[3] Ada Parametric Sizing, Costing and Scheduling, William G. Cheadle, Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201 (paper presented at the 1987 ISPA Conference held 5-7 May in San Diego, CA

[4] SASET Training Course, William G. Cheadle, 16 - 17 December 1992, Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201

[5] DoD Standard 2167A, 29 February 1988, Department of Defense, Washington, DC 20301

the applicable Data Item Descriptions (DID). CDRLs are required contract deliverables and DIDs provide instructions and report formats for CDRL production.

## APPROACH

The initial step in this analysis was to collect and review current information on software development methodologies and scheduling approaches. In addition, applicable DoD and SDIO directives and standards were reviewed to ensure that general requirements affecting cost were included in this analysis. Next, based on the available literature, obligation profiles were developed using nth degree regressions. Finally, the completed profiles were distributed for review by other cost analysts and software estimators to achieve a consensus on the reasonableness of the fiscal year percentages developed for this report.

## ANALYSIS

Software development effort consists of the participation of 4 organizations (System Engineering (SE), Software Engineering (SWE), Test Engineering (TE), and Quality Assurance (QA)) to develop successful, deliverable software systems. Table 1 shows the ratio of each participating organization to the total development effort.

**Table 1. Software Development Organization[6]**

| | | |
|---|---|---|
| Systems Engineering | - | 14 % |
| Software Engineering | - | 66 % |
| Quality Engineer | - | 5 % |
| Test Engineer | - | 15 % |
| Total Software Effort | - | 100% |

Each organization has a specific profile that represents its involvement in a given software project. The spreading profiles, which are given later in Table 4, represent the summation of the 4 separate organization profiles. Each organization profile is based on an nth Degree Least Squares Regression which generates an equation of the form:

$$Y = a_n X^n + a_{n-1} X^{n-1} + a_{n-2} X^{n-2} \ldots + a_1 X + a_0$$

[6] **SASET Training Course**, William G. Cheadle, 16 - 17 December 1992, Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201

The X's and Y's are not straightforward to interpret and are described in further detail.

Y is used to determine the percent of total man-effort for a particular month. Once Y's are determined for all months, each Y must be scaled so that their sum adds to one. This is done by dividing each Y by the sum of all the Y's. For example, if $Y_1$, ..., $Y_{36}$ corresponds to month 1 through 36 in a three year profile, then:

$$\frac{Y_1}{\sum_{i=1}^{36} Y_i}, \frac{Y_2}{\sum_{i=1}^{36} Y_i}, \ldots\ldots, \frac{Y_{36}}{\sum_{i=1}^{36} Y_i}$$

gives the percent of man-effort for each month. Note that these add up to one.

X is a measure of how far a particular month is through the entire cycle. For example, month 1 is $\frac{1}{36}$ of an entire 36 month cycle, month 2 is $\frac{2}{36}$ of the entire cycle, etc. This would naturally give a range of X between 0 and 1. This model, however, uses a range from 0 to 20 for X. Thus, month 18 in a 36 month profile would be given a value of 10 $(10=\frac{1}{2}*20)$ for X since it is halfway through the complete cycle. In general, X is determined by taking the month divided by the total number of months in the cycle all multiplied by 20. For example, the X input for the first month in a three year cycle is $\frac{1}{36}20$, the second month is $\frac{2}{36}20$, through the last month which is $\frac{36}{36}20$. As a further example, the X input for the first month in an eight year (96 month) profile is $\frac{1}{96}20$, the second month is $\frac{2}{96}20$, through the last month which is $\frac{96}{96}20$. It is unclear why a scaling factor of 20 was chosen. One possibility is that a range of 0 to 1 for X gave exceedingly high coefficients in the regression equations.

Each separate organization profile is based on a different regression equation from a data base of over 600 completed software projects.[7] Martin Marietta Denver Aerospace calculated these least square regressions using data taken from the Space and Missile Systems Center

[7] **SASET User's Guide, Version 1.8 and 2.0, Dr. Aaron N. Silver, et.al., 1990 by Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201**

Software Database. The coefficients for each organization are provided in Table 2.

Table 2. Software Development - Manloading Curve Coefficients[8]

| | Y Intercept | 1st Degree | 2nd Degree | 3rd Degree | 4th Degree | 5th Degree |
|---|---|---|---|---|---|---|
| Systems Engineering | 214.41 | -21.03 | 1.04 | -0.02 | 0.0 | 0.0 |
| Software Engineering | 77.72 | -11.18 | 6.90 | -0.82 | 0.036 | -0.00054 |
| Test Engineering | 28.91 | 6.35 | -0.34 | 0.02 | 0.0 | 0.0 |
| Quality Assurance | 77.72 | -11.18 | 6.90 | -0.82 | 0.036 | -0.00054 |

As shown in Table 2, SE and TE profiles were based on 3rd degree regressions, and SWE and QA were based on 5th degree regressions. Table 3, expresses these regressions in equation form.

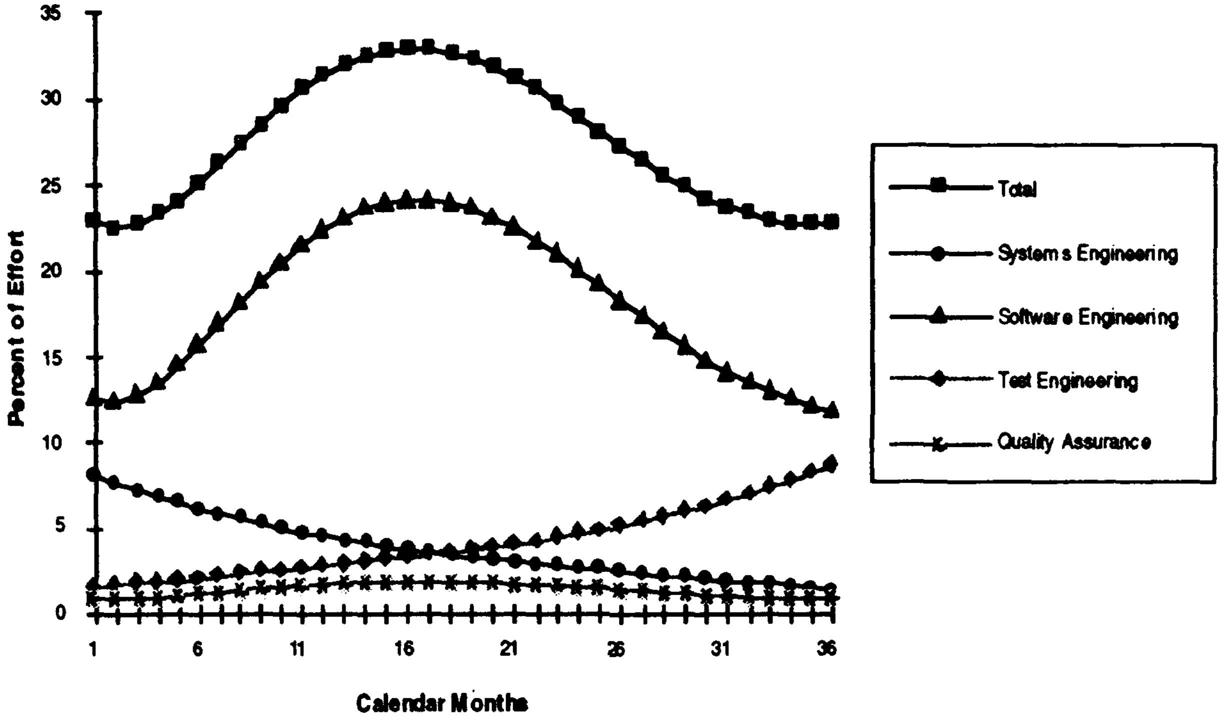
Table 3. Software Development - Manloading Curve Equations[8]

| | |
|---|---|
| Systems Engineering | $Y=214.41-21.03X+1.04X^2-.02X^3$ |
| Software Engineering | $Y=77.72-11.18X + 6.90X^2-.82X^3+.036X^4-.00054X^5$ |
| Test Engineering | $Y=28.41+6.35X-.34X^2+.02X^3$ |
| Quality Assurance | $Y=77.72-11.18X + 6.90X^2-.82X^3+.036X^4-.00054X^5$ |

Figure 4 represents the Manloading curves in a three year spreading profile for each organization and the total effort, based on the equations in Table 3. As stated above, SE and TE profiles are based on 3rd degree polynomials which resemble steadily decreasing and increasing curves respectively. SWE and QA profiles are based on 5th degree polynomials which resemble bell shaped curves. After completion of the organization curves, the four resulting profiles are summed to produce the total profile presented in Table 4.

[8] DBMS Model, Dr. Aaron N. Silver, et.al., 1990 by Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201

Figure 4. Total Manloading by Organization



## RESULTS

This analysis resulted in phasing profiles, presented in Figure 5 and Table 4, that are slightly front loaded, representing the increased requirements and design costs and decreased test costs typical of a DoD-STD-2167A development. Six funding profiles from three to eight years were produced. These time spans were selected because they reflect the range of current CARD DEMVAL and EMD schedules and will allow cost analysts the flexibility to choose a profile that fits their specific project estimate.

**Figure 5. Software Spreading Curves - Percent by Fiscal Year**

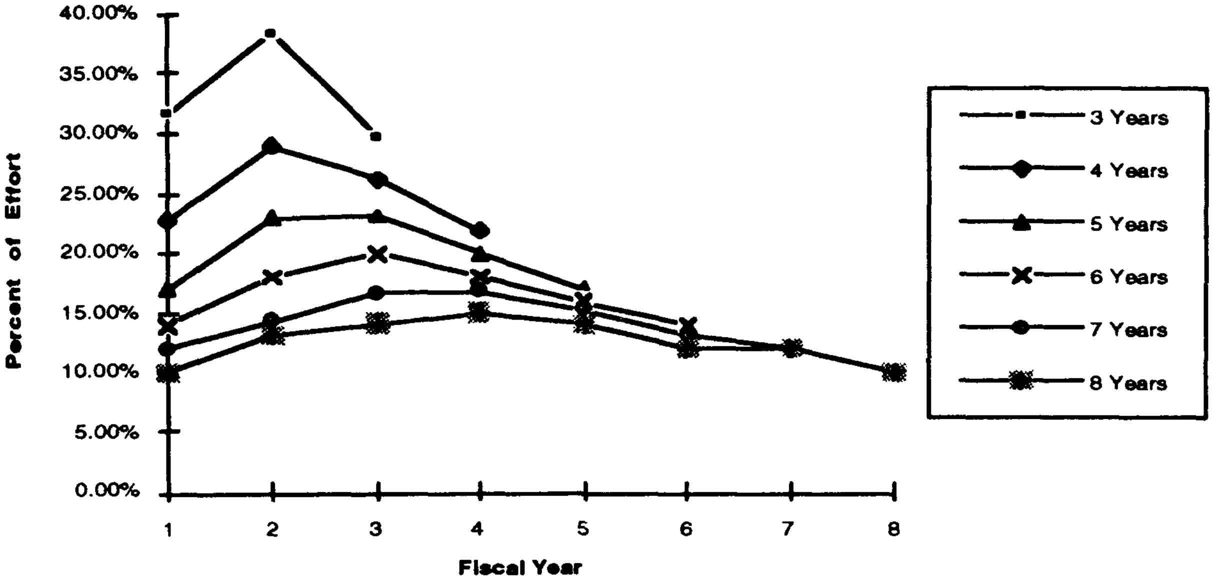


Figure 5 is included in this report to illustrate curve shapes created by the annual percentages provided in Table 3.

**Table 4. Time Phasing Factors**

| | FY 1 | FY 2 | FY 3 | FY 4 | FY 5 | FY 6 | FY 7 | FY 8 |
|---|---|---|---|---|---|---|---|---|
| 3 Years | 32% | 38% | 30% | | | | | |
| 4 Years | 23% | 29% | 26% | 22% | | | | |
| 5 Years | 17% | 23% | 23% | 20% | 17% | | | |
| 6 Years | 14% | 18% | 20% | 18% | 16% | 14% | | |
| 7 Years | 12% | 14% | 17% | 17% | 15% | 13% | 12% | |
| 8 Years | 10% | 13% | 14% | 15% | 14% | 12% | 12% | 10% |

These percentages represent effort starting on 1 October. Fiscal year percentages should be adjusted for projects that start later in the fiscal year. A simple proration is the best approach. For example:

Year 1 Factor* months in first fiscal year $/_{12}$ months = partial fiscal year factor

As an example, a six year profile, starting mid-year, would require that the analyst use a partial year factor for the first and last years in the profile. Using the six year profile factors and the formula alone, the analyst would calculate:

$$14\% * \frac{6}{12} = 7\%$$

Based on this approach, seven percent of the effort would be placed in the first and last years of the fiscal year profile.

## CONCLUSIONS/RECOMMENDATIONS

The equations provided in this report can be used in any automated spreadsheet application. All that is required is total software development effort and total required months to produce a software development profile. The analyst should rely on an accepted method of estimating total effort and schedule months to ensure the creation of an achievable cost estimate. Successful completion of a given software development project is solely dependent on the optimum effort spread over the optimum schedule. Any variations almost always cause performance problems.

These equations will be input into ARSEM/SPARC to be used as our standard software spreading approach.

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**SASET Training Course**, William G. Cheadle, 16 - 17 December 1992, Martin Marietta Denver Aerospace Corporation, PO Box 179, Denver, CO 80201

## List of Acronyms

CARD — Cost Analysis Requirements Document

CDR — Critical Design Review - at this review, the contractor must present his build to design for customer approval. Typically conducted for each configuration item when detail design is essentially complete. Once this review is completed, coding can begin.

CDRL — Contract Deliverable Requirements List - a list of the products, due dates, and distribution requirements assigned by the customer on a given contract.

CSC — Computer Software Component -a distinct part of a computer software configuration item (CSCI). CSCs may be further decomposed into other CSCs and CSUs. CSCs are usually limited to approximately 5,000 SLOC for a large system.

CSU — Computer Software Unit - An element specified in the design of a CSC that is separately testable. It is the smallest building block or component of a software system. Usually limited to 75 to 100 source lines of code.

CSCI — Computer Software Configuration Item - the CSCI is the reportable configuration item, with DoD-STD-2167A documentation requirements. The CSCI typically consists of several CSCs with an optimum size of 50,000 SLOC or less in a large software system.

DID — Data Item Description - the DID provides the report format required for CDRLs.

DoD — Department of Defense

FCA/PCA — Functional Configuration Audit/Physical Configuration Audit - FCA is a formal audit to validate that the development of a configuration item has been completed satisfactorily and that the configuration item has achieved the performance and functional characteristics specified in the functional or allocated configuration identification. PCA is a technical examination of a designated configuration item to verify that the configuration item "As Built" conforms to the technical documentation which defines the configuration item.

## List of Acronyms (continued)

Firmware The combination of a hardware device and computer instructions or computer data that reside as read-only software on the hardware device. The software cannot be readily modified under program control.

FQR Functional Qualification Review - the objective of the FQR is to verify that the actual performance of the configuration items of the system as determined through test comply with the requirements specification and to identify the test reports/data which document results of qualification tests of the configuration items.

ROM Rough-Order-of-Magnitude - a cost estimate with a fidelity of 25 percent.

SASET Software Architecture Sizing and Estimating Tool - a software cost estimating model designed by Martin Marietta for the U.S. Navy.

SDR System Design Review - conducted as the final review prior to the submittal of the DEMVAL Phase products or as the initial EMD review for systems not requiring a formal DEMVAL Phase. Consists of a review of the System Engineering Management Activities, results of trade studies, and other updated design requirements.

SDIO Strategic Defense Initiative Office - PM for SDIO programs.

SLOC Source Lines of Code - consist of all executable statements. Accounting by type: format statements, data declaration statements, common declarations, dimensions, deliverable job control language statements and procedure oriented language statements.

SPR Software Planning Review - conducted shortly after contract award to provide the customer with an updated Software Development Plan.

## List of Acronyms (continued)

SRR System Requirements Review - can be conducted any time, but normally conducted after accomplishment of functional analysis and preliminary requirements allocation to determine initial direction and progress of the contractor's System Engineering Management effort and his convergence upon an optimum and complete configuration.

SSR Software Specification Review - usually conducted during system concept after accomplishment of functional analysis and preliminary requirements allocation to configuration items.

TRR Test Readiness Review - conducted for each CSCI to determine whether the software test procedures are complete and to assure that the contractor is prepared for formal CSCI testing.